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The automotive battery of the future—the role of electronics

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Abstract

The automotive battery is being asked to carry out more challenging duties than ever before. Many of these duties are a result of new types of electrical load. The way in which a battery is operated and managed within a vehicle can be optimized significantly through the use of battery-related electronics with embedded software. Potential benefits include extended life, early warning of deterioration and failure, greater availability and an improved match to the vehicle's requirements. The impact of electronics in other areas shows that there is considerable potential to go much further in this direction with battery systems. There are, however, important system-wide issues to be considered. The battery system must conform to a wide range of standards and practices applicable to automotive electronic systems and embedded software. The automotive industry is itself trying to come to terms with the inherent difficulties involved in developing, qualifying and upgrading complex networks of software-based controllers within the vehicle. The battery system must be compatible with the results of these initiatives. Cost will always be a major influence, but the cost model is different from that familiar to battery producers. This study outlines the main areas where the battery industry must consider a change from being a component to a system supplier, and makes some recommendations for an industry wide approach to smooth the transition.

Keywords: Automotive battery; Electronic systems; Vehicle power-supply; Load; powerNet; Management system

1. Introduction

The majority of developments in the automotive sector are either complete electronic systems or systems that have some measure of electronic control. Various authors, e.g., Nicastri and Huang [1], have highlighted the movements in this area and have classified the new or improved systems into categories such as control systems, information systems, entertainment systems, and communication systems. To date, most of the literature concerned with the power supplies for this electronics has concentrated on the higher power loads and the possible emergence of a new 36-V/42-V standard. This would supplement and potentially eventually replace the existing, almost universal 12-V system, but is evolving much more slowly than anticipated because of high introduction costs. This paper takes a rather different look at some of the less obvious impacts of these emerging electronics systems on the battery. If explores whether parallels can be drawn from developments in other areas, and if there are opportunities to take steps now that will smooth the path ahead.

2. Some selected background information on the electronics industry

It is helpful to understand the business drivers in the electronics sector. The electronics components industry is largely a materials industry, with some parallels to the lead industry and some major differences. The key material is ultra high purity (150 parts per trillion) single-crystal silicon. This is grown in ingots using Czochralski pullers, which can take up to a month to grow a modern 300-mm diameter ingot. The process is shown in Fig. 1 [2]. Hyperpure silicon costs around US$ 3500 per kg, which is remarkable for processed sand.

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Fig. 1. Hyperpure silicon ingot in Czochralski puller—(source: SVMI).

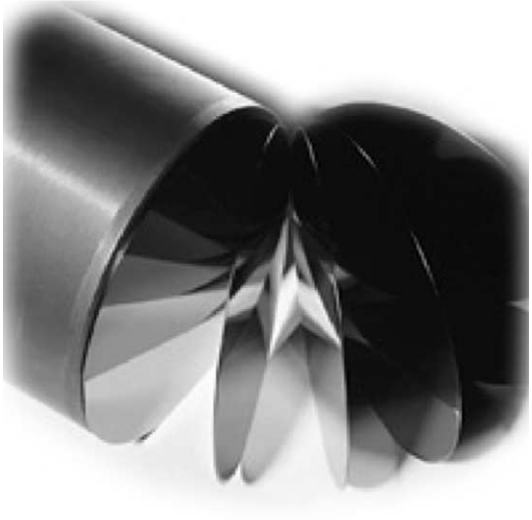

Fig. 2. Silicon wafers after slicing, lapping and polishing—(source: SVMI).

Once grown, the ingot is sawn into wafers using a diamond-edged saw, then lapped and polished under very clean conditions to a mirror finish, Fig. 2. The final wafers are 650-μm thick. There are five main players in the wafer production market, mainly Japanese. Between them, they produce around 800 000 300-mm diameter wafers per month. A single, unprocessed wafer costs in the region of US$ 200 [3] and there will be several hundred integrated circuits per wafer.

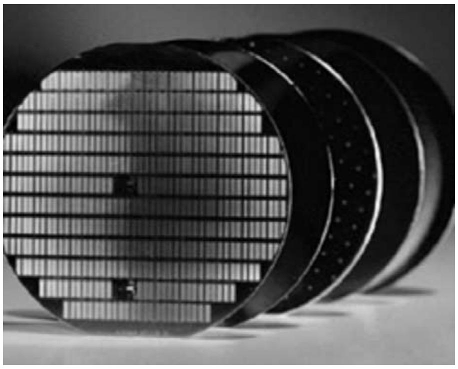

Fig. 3. Processed silicon wafer—(source: Intel).

The wafers are then processed by selective doping to make the familiar complex structures, Fig. 3. As an illustration of the advance in the last >30 years. An original 2300 transistor, 0.8-MHz Intel 4004 from 1971 is compared in Fig. 4 with a contemporary 125 million transitior 3600-MHz Pentium IV HT [4]. During this time-line, features have shrunk from 10 μm to today’s 90 nm, i.e., a 100-fold reduction. Moore’s law [5] is all the better as it is based on minimum component cost, not technological progress alone. This tremendous progress has only been possible because of very large investments in plant. Today, a typical 90-nm capability 300-mm wafer facilities costs US$ 3 billion to build. Typical integrated-circuit design costs are in the US$ 20 million range [6–8], so the parts are only very cheap in high volume. The use of low-cost materials is just as important as with batteries in keeping volume costs down. In high volume, the package cost can dominate the cost of the far more sophisticated silicon. Rather like the battery industry, there is a considerable

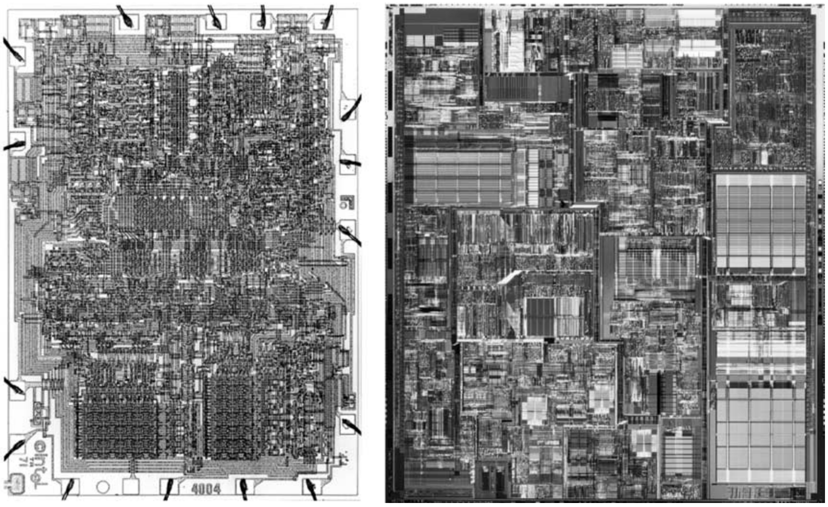

Fig. 4. Intel 4004 die in 1971 compared with contemporary Pentium IV die—(source: Intel).

divide between those who manufacture the parts and those who use them.

One consequence of the very high capital and fixed design costs is that very few parts are built speculatively. Almost all parts are manufactured for, and largely specified by, a single large end customer. The silicon vendor will, however, generally retain the right to sell parts to others. This is an essential part of the industry as high volumes are crucial to keep prices to a commercially attractive level. A further important point is that the industry, both at the silicon design and application levels, needs several sophisticated development tools. The development cost of these has to be spread over as many users as possible, but it is not uncommon to find tools costing well over US$ 100 000. This can be a very lucrative area for those whose tools become industry standards.

3. Changes in vehicle power-supply requirements

Electronic systems are the cause of most of the changes imposed on the vehicle battery. It is interesting examine the several factors that are changing in addition to the increase in load power.

3.1. Number of loads

There has been a large increase in the number of loads per vehicle and this is very likely to continue [9]. Most modern cars have several fuse boxes and several loads per fuse. Across a model range there is a significant range of optional fitments, and therefore, a wide range of possible power-supply networks has to be developed, tested, managed and maintained.

3.2. Load characteristics

The move from mechanically to electronically switched loads is well under way, with pure electronic systems at relatively low power levels and potentially several new high power loads [10]. Loads are increasingly becoming multi-level or continuously variable rather than on/off [9,10]. Some of the differences between typical loads that are significant to the power system designer are shown in Fig. 5.

3.3. Load sensitivities

The topic of electromagnetic compatibility (EMC) is now a key part of automotive electronic system development. Stringent limits are imposed on sub-systems in an attempt to avoid problems with interference from adjacent and interconnecting networks. The power supply system is the most invasive network on the vehicle and has an important influence on this. This is evidenced by the much more sophisticated grounding design in current vehicles. It is likely that this will have an increasing influence on the design of everything connected to the powerNet and its components, and to the sub-systems themselves.

3.4. Load level diversity

There is already a very large range of possible power levels to be resourced. This includes both engine-on and engine-off loads and many possible combinations based on duty, ambient conditions and driver preferences. Because satisfying the worst case conditions will lead to a very expensive solution, it is likely that some measures to alleviate the maximum requirements will be taken [11–13].

3.5. Load criticality

Some of the new loads, such as electro-hydraulic brakes and drive-by-wire primary controls, introduce new levels of safety requirements on the power-supply system [14]. This has already resulted in a demand from regulatory authorities for battery monitoring on some advanced vehicles. There is

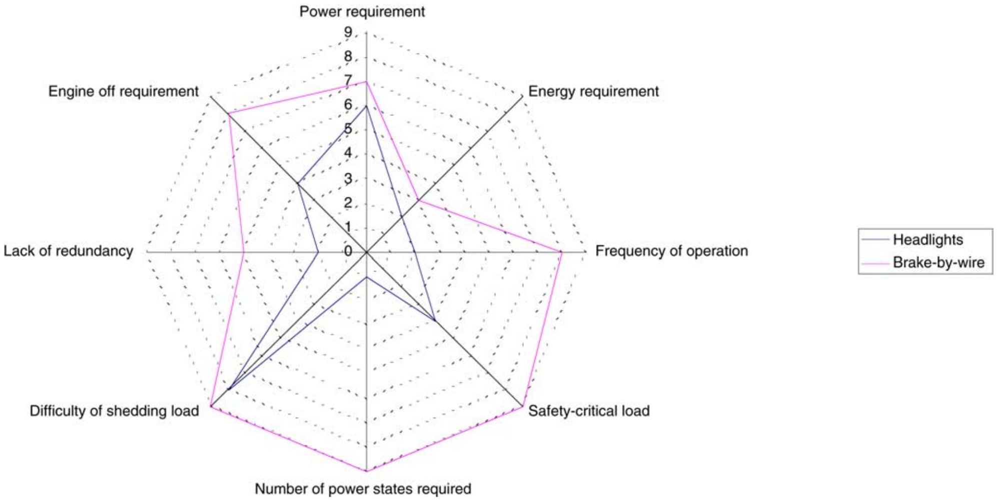

Fig. 5. Comparison between historic and modern load characteristics.

also a need to be able to prioritise high-criticality loads in the event of a power shortage. For example, a vehicle using brake and steer-by-wire must be able to deal with an alternator failure when travelling at high speed on a dark, cold and rainy night without losing power to any critical system.

3.6. Technology issues

Modern electronic components are moving to lower system voltages internally as this allows greater silicon integration and hence lower unit cost. This can lead to a demand for relatively high supply currents at low voltages which complicates the power supply design. For example, a Pentium IV takes up to 120 A at around 1.4 V, and has a mean power dissipation of 100 W.

The cost of the power supply is also strongly influenced by the requirement on allowable level range for the input voltage. It would be attractive to limit the range to a narrow band, but this is difficult with the diversity of power loads on the 12-V rail.

The high costs of developing electronic systems is causing manufacturers to find ways to co-operate in those ‘infrastructure’ areas with little visibility to the end customer. Initiatives such as AUTOSAR [15] are attempting to standardize the basic building blocks of the electronic architecture. The benefits in reducing development cost and timescale are clear. A similar strategy has been in place for some time with computer systems. A relevant example here is the SMBus [16] interface to the battery packs in laptop computers. This standard is widely adopted and greatly simplifies the task of interfacing between the battery and the electronic system. It also creates a market opportunity for third-party companies [17] and has been a key factor in the growth of the electronics industry.

The general increase in attention to liability issues will involve more organizations with safety case preparation and this is likely to include all aspects of the battery system. This becomes much more arduous as complexity increases.

4. Electronics as part of the solution

As well as being the cause of most of the new requirements, electronics can offer several solutions to help satisfy these requirements. Nevertheless, successful introduction of these new solutions needs a different, system-based approach to the development of power systems. This will require some changes in the battery industry.

4.1. Power/energy management

It is relatively straightforward to switch the power feeds to different classes of loads, as illustrated in Fig. 6, so that these may be prioritized and/or managed in times of power shortage [12,13]. There will always be some power loss from doing this, though this can be held to very low levels with modern switching devices. As part of the power switch, it is easy to add some protection and monitoring features at low additional cost.

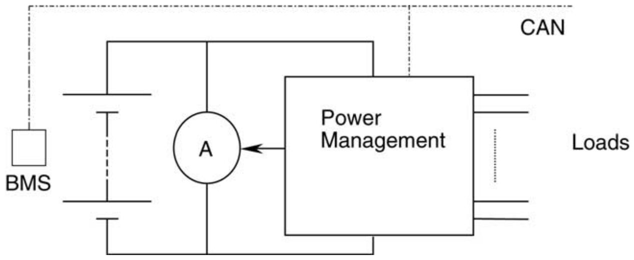

Fig. 6. Power management system.

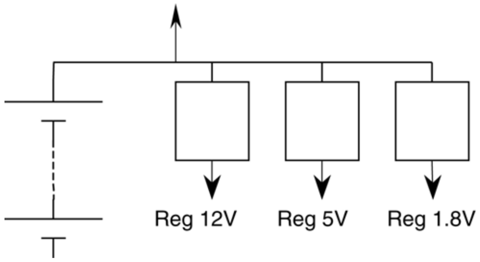

Fig. 7. Multi-rail power conditioning system.

It is also possible to command the various control systems to reduce their power demands to meet the overall need, but requires the load units to be designed to respond to this request. This would ideally take account of the state-of-function [12] of the battery. Power flow to–from the battery can also be controlled to manage the energy stored on the vehicle.

These approaches require some knowledge of the state of the battery, which implies that an electronic battery management system is used [12]. Ideally, this would be fully integrated with the vehicle’s power-management system.

4.2. Power conditioning

Most electronic equipment has several power rails to deal with different types of load. A sophisticated microcontroller might require a tightly controlled low voltage at high current. (For example, the 3.6-GHz Pentium mentioned earlier requires a voltage controlled to a commanded voltage that is accurate to 10 mV in the range 1.2–1.6 V.) A simple load, such as a light, will have a much less stringent requirement.

In a car, it is attractive to consider splitting the high specification rails from the others (Fig. 7) so as to condition each critical rail to a tighter voltage tolerance and to a lower noise level. This would lower the cost of each ECUs power supply and reduces the potential for interaction. There are also some moves towards redundant systems and this will inevitably involve the battery systems (Fig. 8).

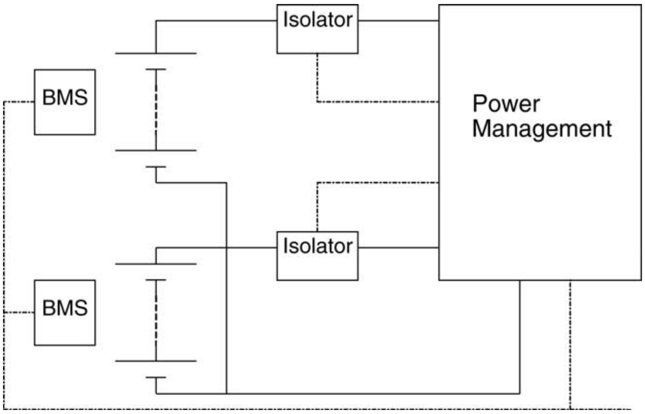

Fig. 8. Redundant battery system.

5. Electronics as a source of unfamiliar constraints

There are significant differences between the battery industry and the electronics industry. In particular:

- there is a radical difference in the speed of product cycles and hence more opportunities to gain (and lose) market differentiation;
- electronics with embedded software is highly complex and has a correspondingly complex development approach; this is also continually evolving to overcome problems and make the process more efficient;
- the electronics industry can generally offer very low unit costs in high volume, but tends to have much higher development costs;
- the electronics industry is by its very nature highly integrated and a systems approach is the key to success;
- the majority of the electronics industry is based on repeatable, very well understood technology and highly characterized components;
- electronics components are in general not subject to deterioration with time or use;
- standards are an essential part of the whole industry.

Because of the difference in the business models it is likely to be difficult for battery companies to move into developing electronic products or sub-systems. This was the experience of the automotive industry in general, which initially adopted a proprietary approach and concentrated too much on low unit cost and not enough on total cost. The auto companies are now among the leaders in system thinking and efficient development, and are major specifiers of advanced components. They are consequently demanding customers.

Experience has shown, however, that those industries who do not make the transition to encompass electronic systems within their products create profitable opportunities for new companies to exploit and can themselves be forced into a commodity position.

6. Opportunities for the battery industry

The battery industry's automotive (and possible total) future is intimately tied up with electronic systems so there is considerable motivation to make the best of this. It is likely that someone will be a Tier 1 supplier of power-supply systems to vehicle OEMs; does the battery industry want to supply cells to a Tier 1 supplier, or be the Tier 1 supplier themselves? Some ideas to smooth the path might be as follows:

- Creation of some industry-wide standards for vehicle battery management (cf., SMBus) interfaces in co-operation with the automotive industry [16].
- Consider the requirement to be the 'supply of power' and develop standard interfaces to the rest of the vehicle with possibly several voltage rails, some dedicated to powering sensitive ECU loads.
- Jointly develop a hardware/software platform for battery management so that third-party vendors or individual companies can offer modelling algorithms that are compatible with this. This will need standardized interfaces to the rest of the vehicle. This approach is totally in line with initiatives like Autosar and builds on previous work on standard communications approaches like CAN.

7. Conclusions

The future of the battery industry in interlinked with developments in automotive electronics. This can either be seen as an opportunity and exploited, or left to others to exploit. There are many lessons to be learned from developments in other industries. These suggest a need to understand the electronics industry and its issues, to recognize the importance of well thought through standards, and to consider the benefits of co-operative working on the infrastructure.

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